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EUV optical elements with enhanced spectral selectivity for IR radiation

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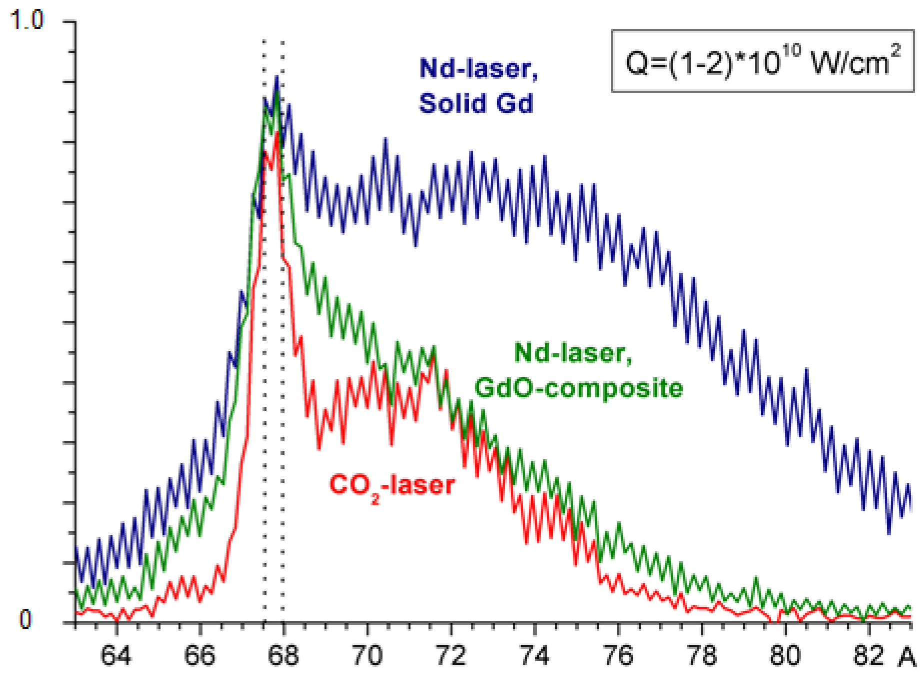
XLIV OPTICS

Outline

- Scattered IR radiation in 6.x nm radiation sources
- IR suppression strategies
- First experimental results
  - EUV reflection
  - IR suppression
- Summary

Plasma-based sources of 6.x nm radiation

Gd-based LPP emission spectra



CO_2 laser provides highest CE and spectral purity

ISAN: poster S46 this conference

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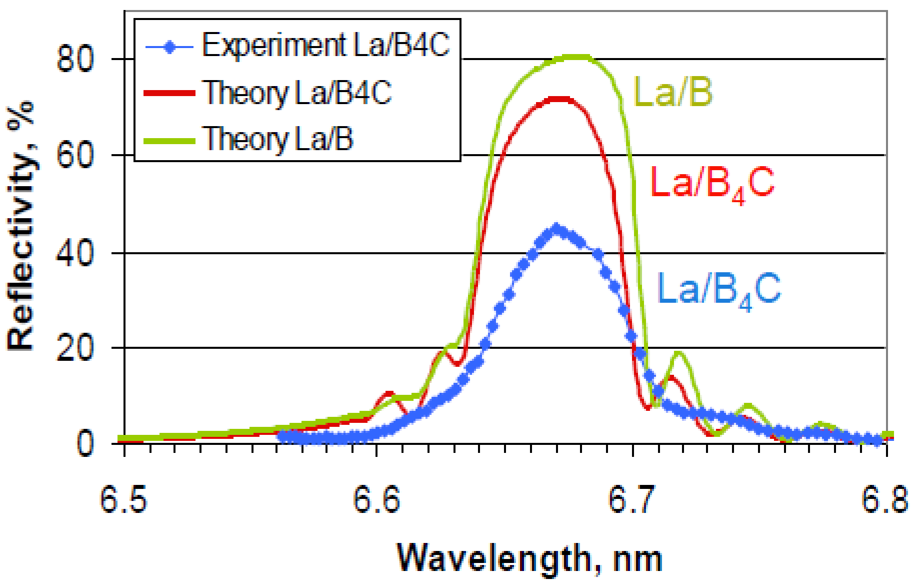
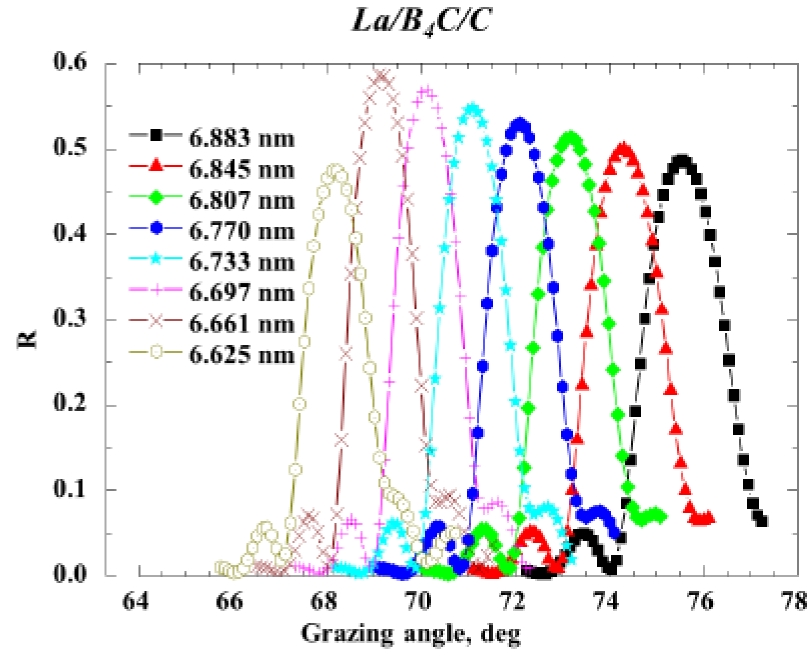
Multilayer optics for 6.x nm radiation

MLM reflectivity (200 bi-layers)



MLM with carbon anti-diffusion layers, fabricated at IPM RAS / X-Ray.



Appl. Phys. Lett. **102**, 011602 (2013)

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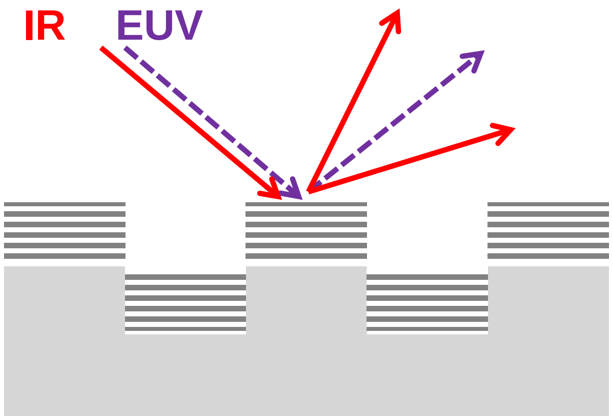
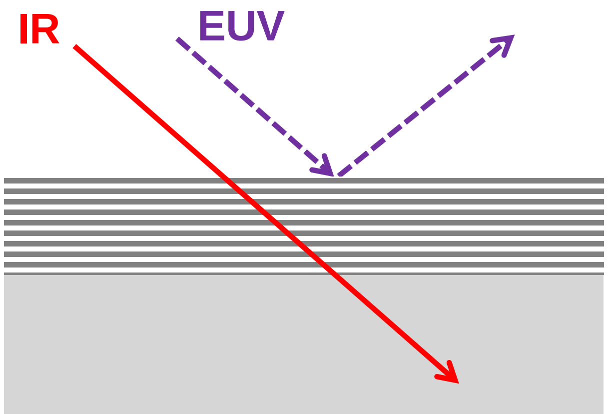
Possible IR suppression strategies





Both designs provide strong IR suppression

Design with min. EUV losses = proper choice

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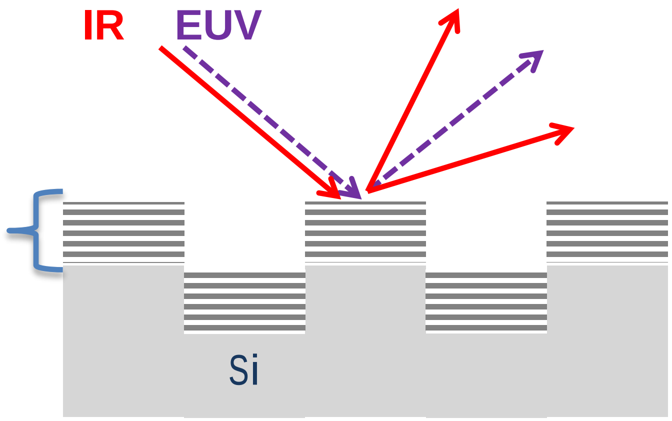
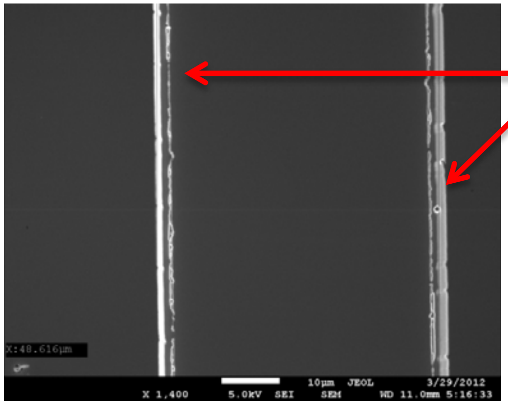
Multilayer gratings for 13.5 nm



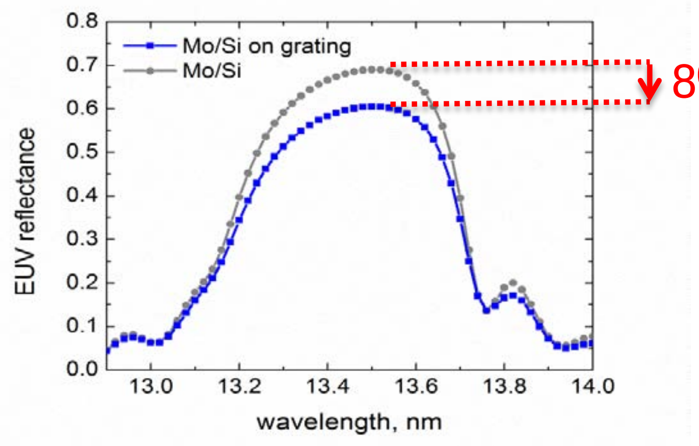
SEM top view of Mo/Si coated Si grating



V.V. Medvedev et al., *Opt. Express* **21** 16964 (2013)

Scaling for 6.x nm optics?

Similar/higher level of EUV reflectivity losses is expected



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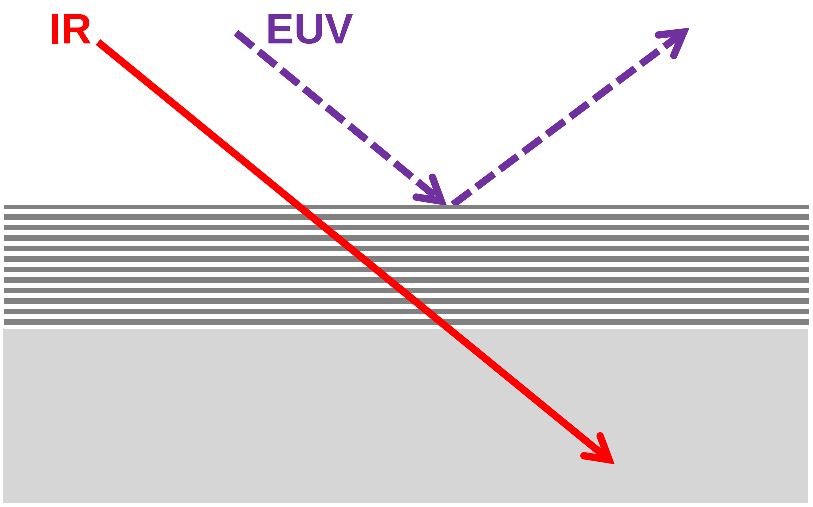
EUV reflection + IR antireflection

Application of antireflection-based 6.x nm optics design may be advantageous for maintaining highest possible EUV throughput

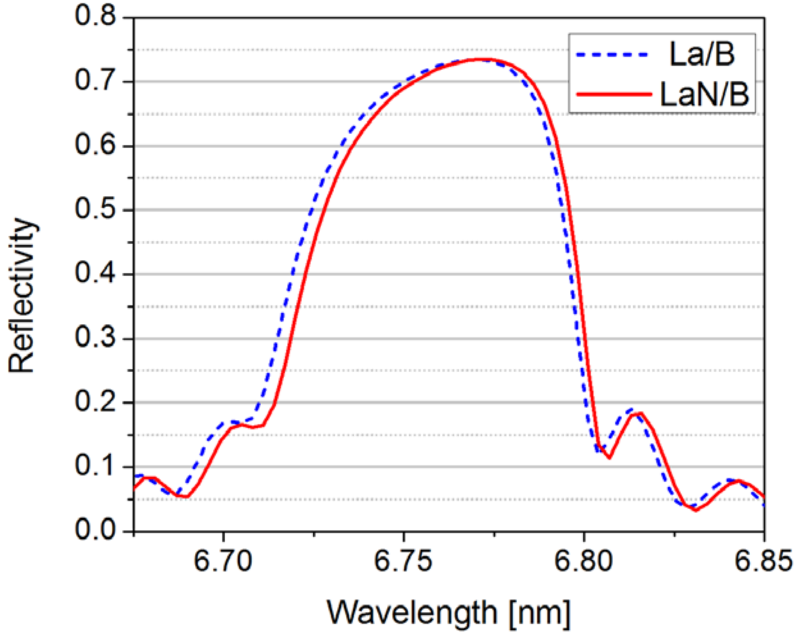


!But La/B and La/B4C coatings are opaque for IR radiation

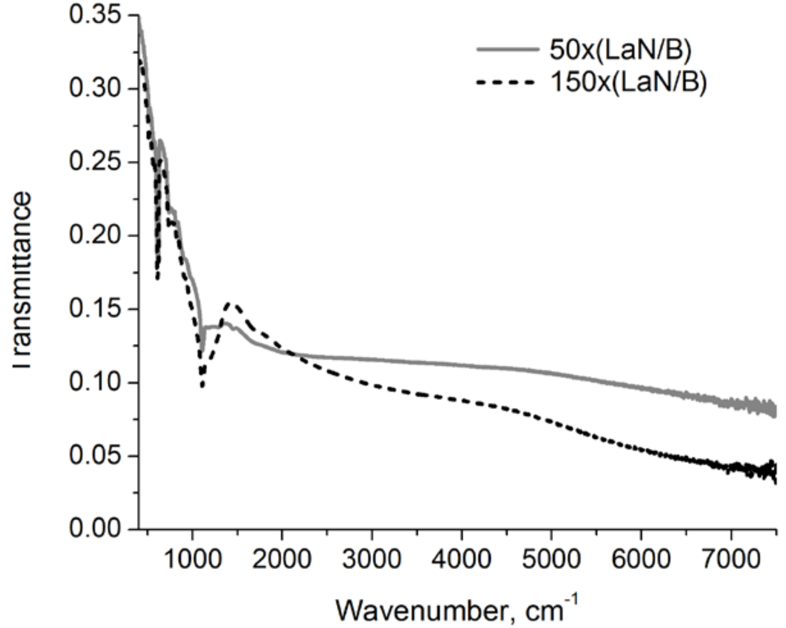
➡ IR transparent materials are required

IR transparent LaN/B multilayers

Calculated EUV reflectivity



FTIR measured IR transmission



LaN/B vs La/B:

- ❑ Equal 6.x reflectivity
- ❑ LaN/B multilayers are IR transparent → antireflection designs are possible

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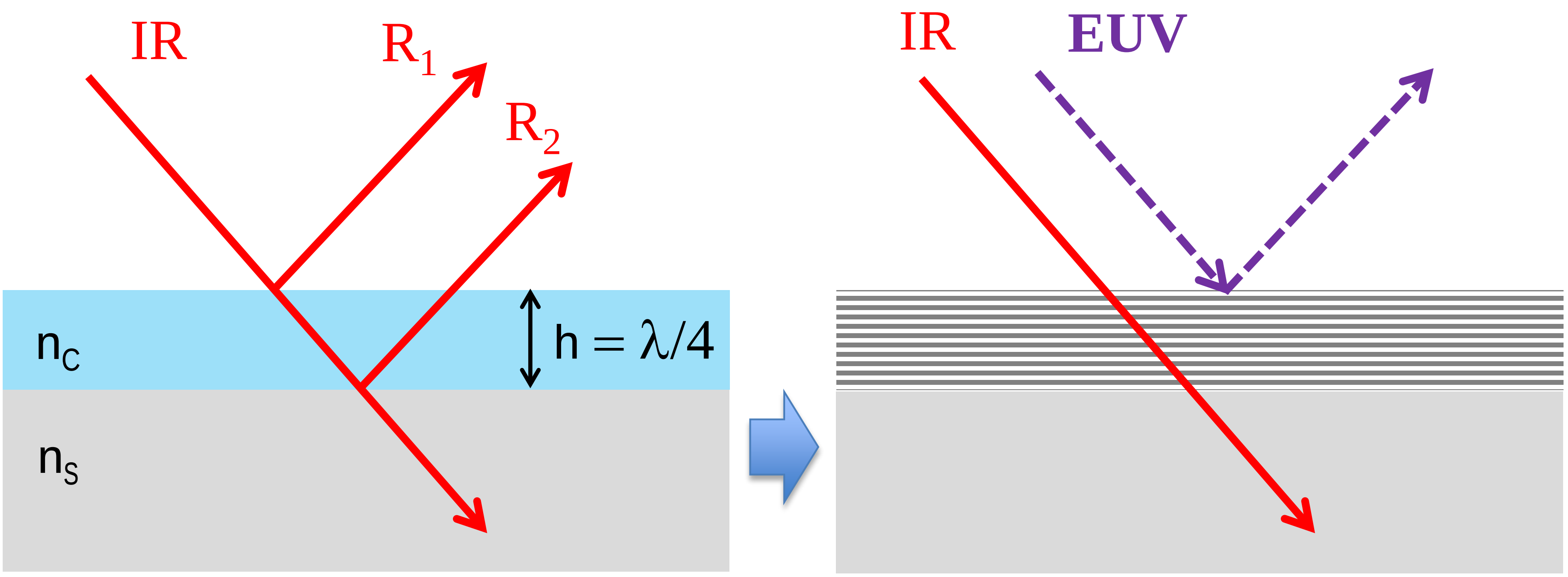
Classical antireflection design



R_1=R_2 requires perfect matching of refractive indices **$n_C=(n_S)^{1/2}$**

IR properties of LaN/B multilayers

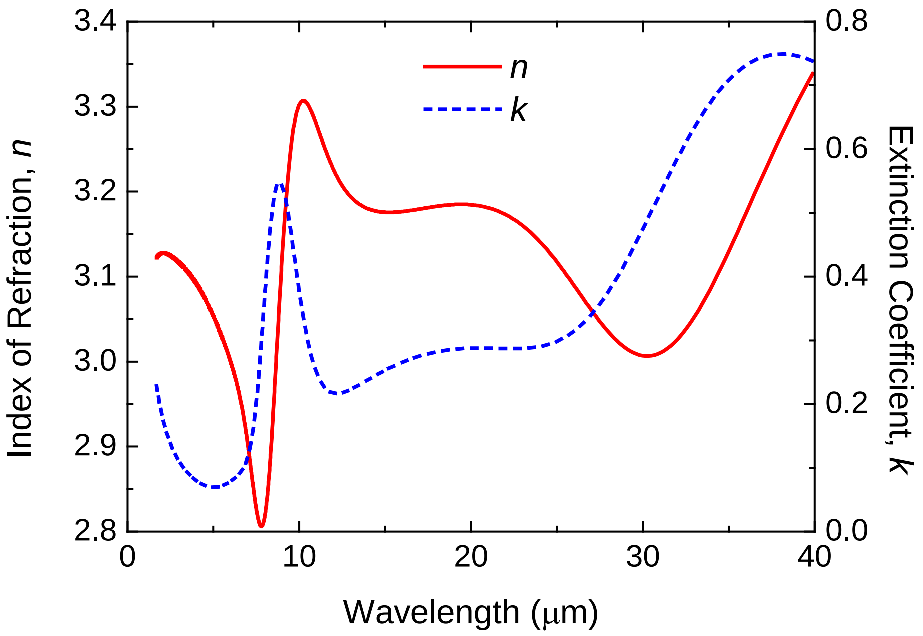
IR optical constants are required for AR coating design

IR spectroscopic ellipsometry:

Measured n,k for LaN/B multilayer

Effective medium approximation

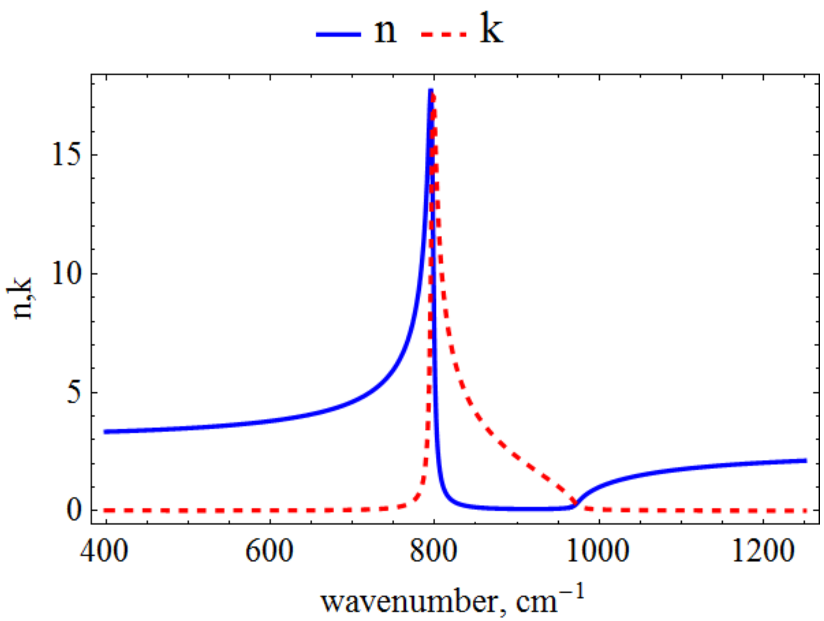
n = 3.3+0.3i for λ = 10.6 μm

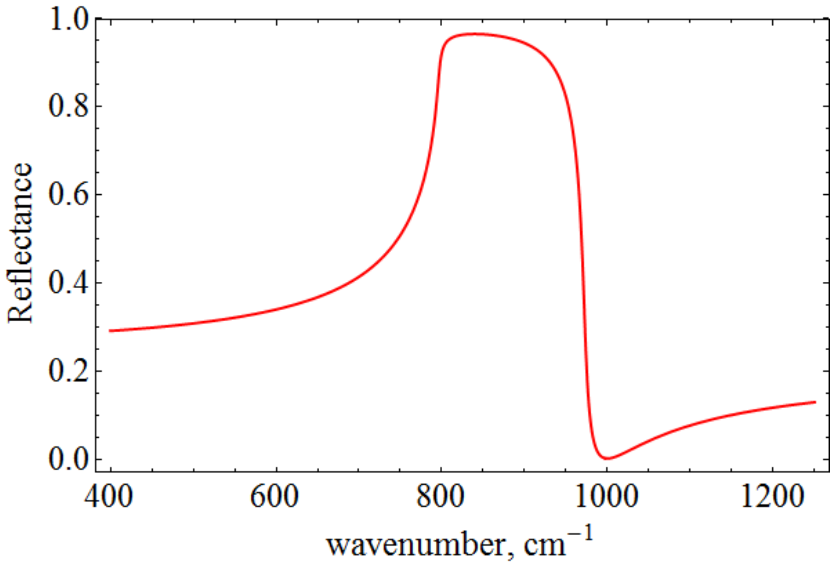


Required substrate n=11

Materials with such n values do not exist

SiC as a substrate material

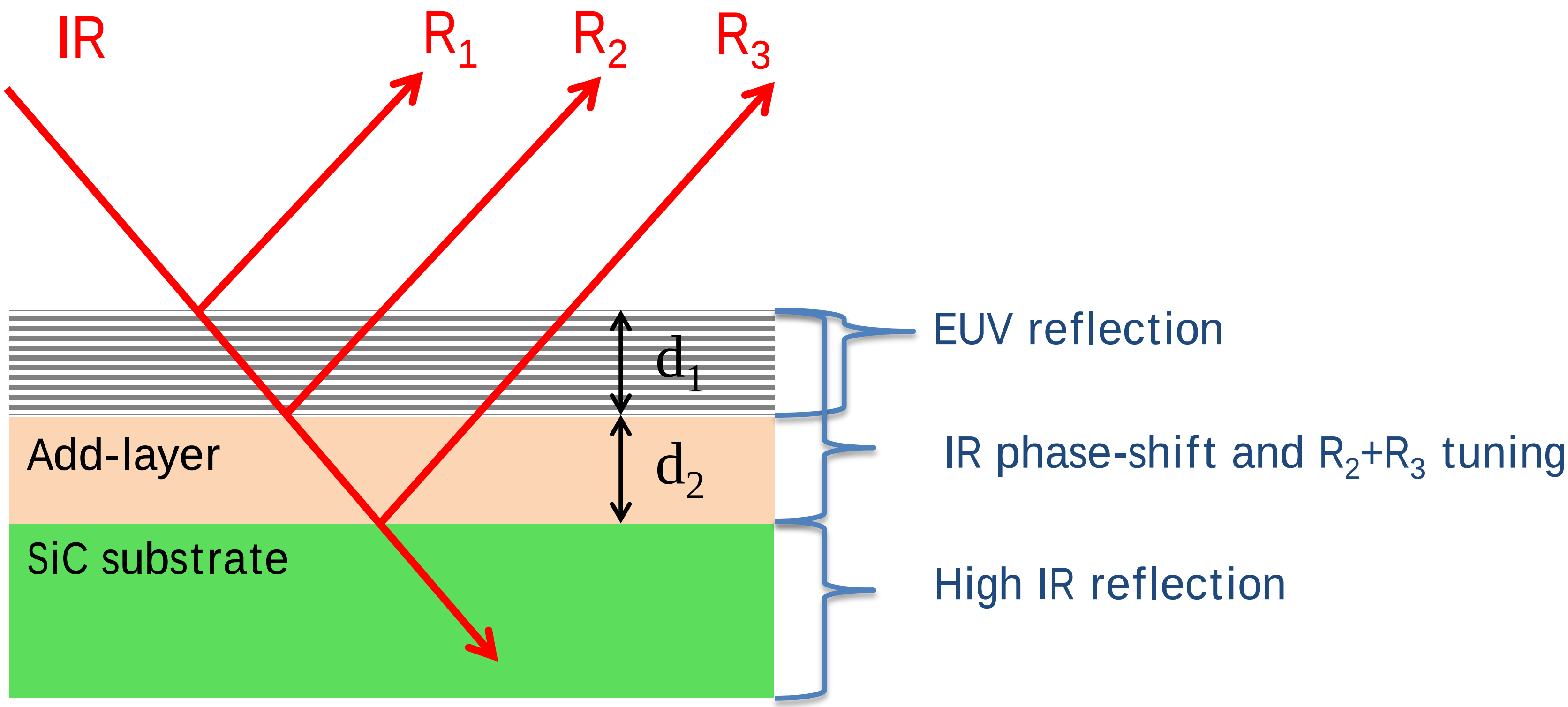




High reflectance in mid infrared due to phonon-assisted resonance
→ Can be applied as a substrate material for LaN/B-baser AR coating

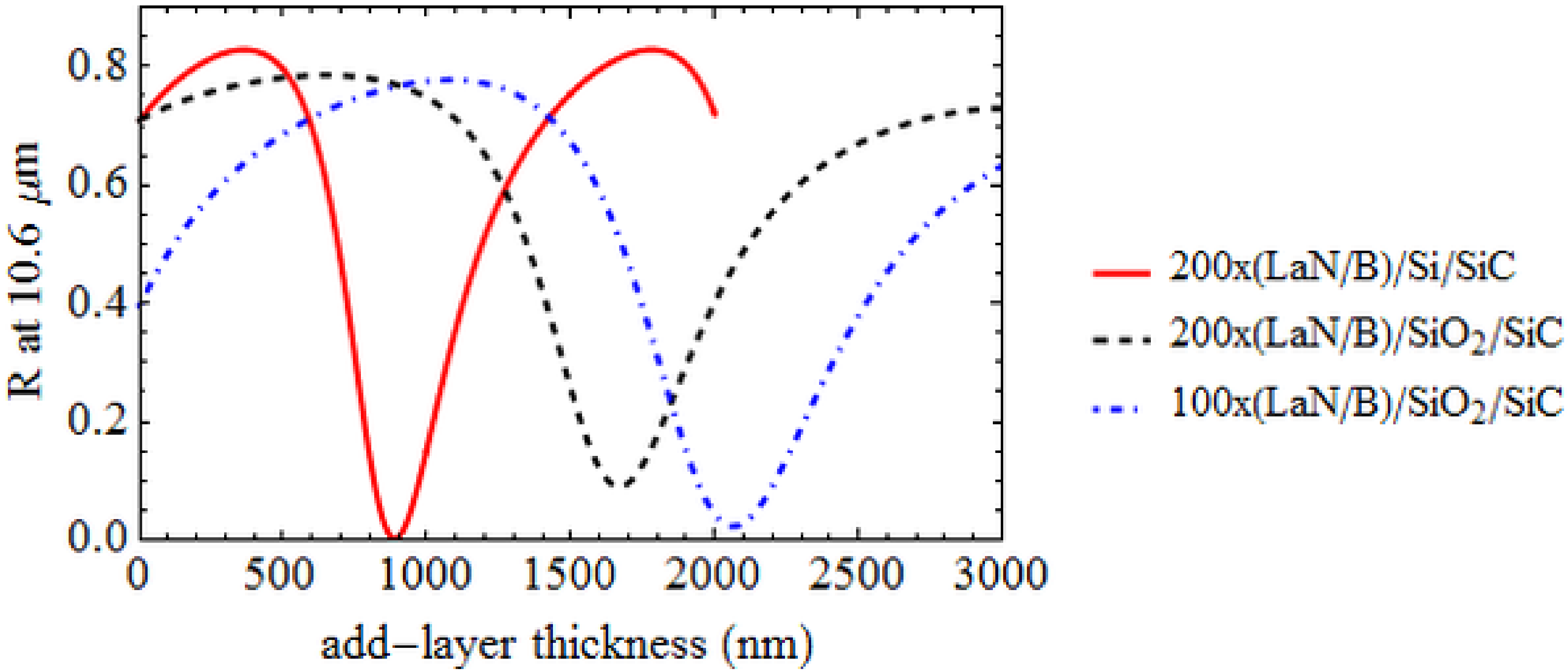
SiC is already known as suitable for EUV multilayer deposition
Ref: Soufli et al *Proc. SPIE* **8501**, 850102 (2012)

Alternative antireflection design



Add-layer: materials compatible with ultra-smooth growth should be used, e.g. a-SiO2, a-Si,...

Design calculations

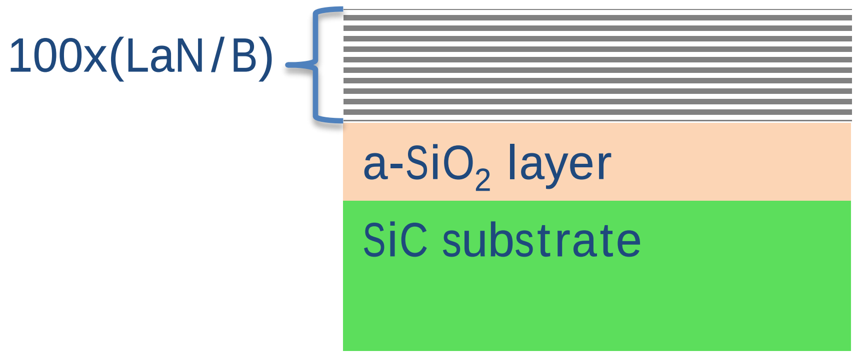


Si add-layer: 250× IR suppression with 200x(LaN/B) bi-layers

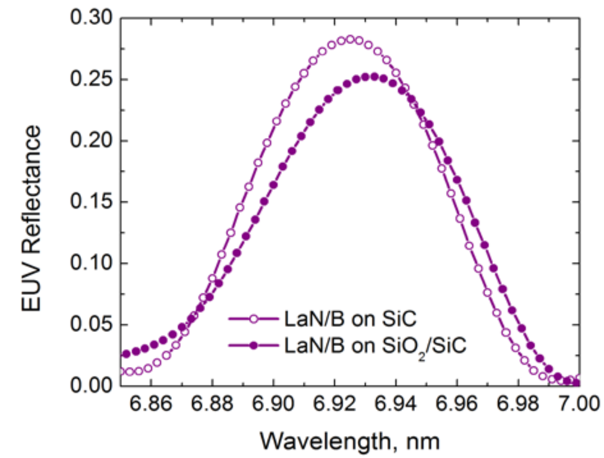
SiO_2 add-layer: 10× IR suppression with 200x(LaN/B) bi-layers (lower due to redundant wave attenuation inside SiO_2 layer)

Design #2: Experimental results

Test coatings:



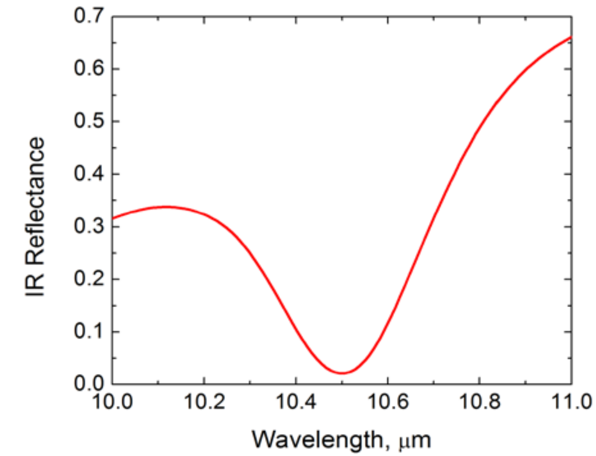
EUV reflectivity measurements (PTB)



1. CVD deposition of SiO_2 layer on α-SiC(0001) by Gooch and Housego LLC
2. Magnetron deposition of LaN/B ml

FT-IR reflectivity measurements

Measured 50x IR suppression



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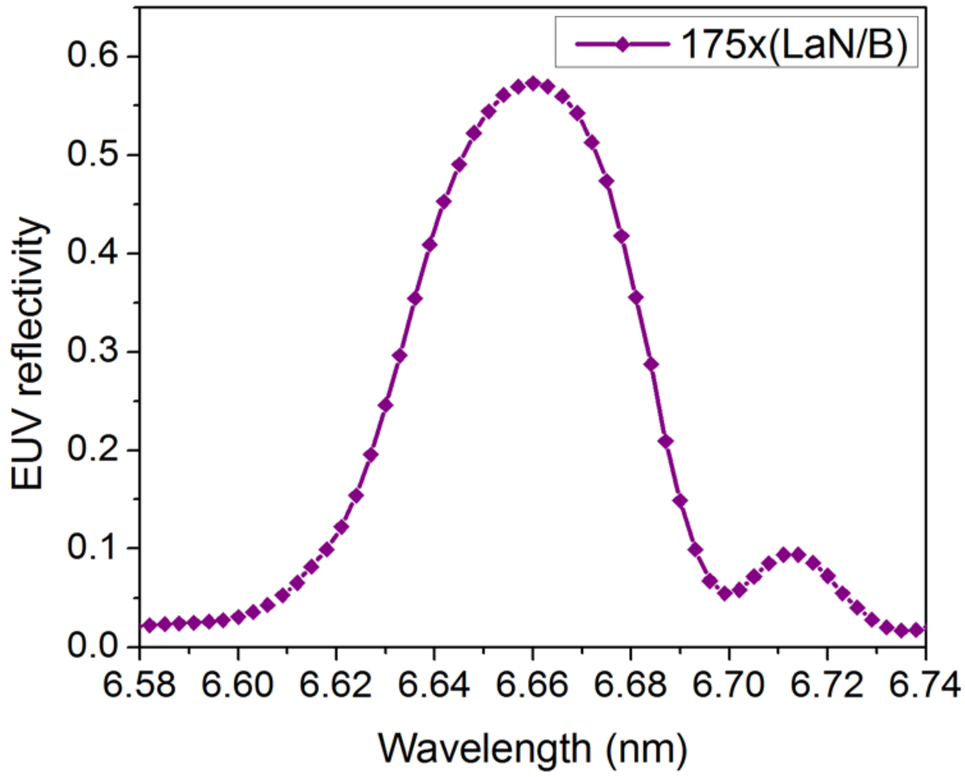
State of art EUV reflectivity with LaN/B



Makhotkin et al. "Short period La/B and LaN/B multilayer mirrors for ~ 6.8 nm wavelength," submitted

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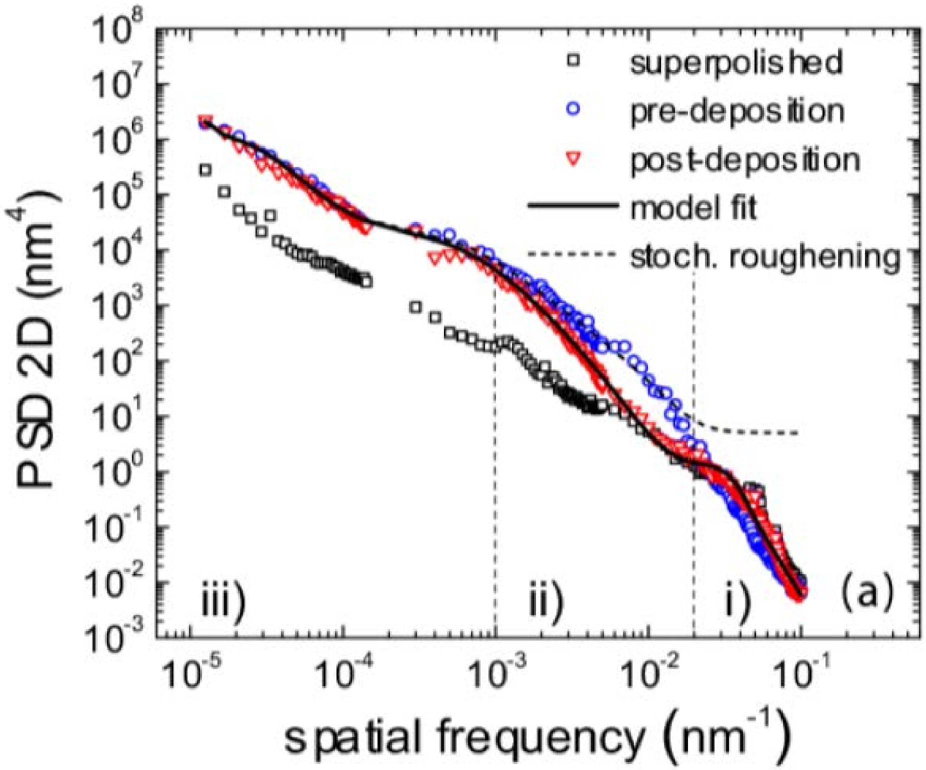
How to grow ultrasmooth Si add-layer

Deposition of ultrasmooth μm-scale a-Si layers for 6.x nm optics is under development



A.J.R. van den Boogaard et al, J. Vac. Sci. Technol. A **28**, 552 (2010)

Summary

- Design of multilayer mirror providing simultaneously high reflection at 6.x nm radiation and with near-zero IR reflection has been proposed

- Test coatings for the proof of principle have been manufactured
  - 50x IR suppression demonstrated
  - 25% EUV reflection demonstrated

- Further increase of mirror performance is possible with a-Si add-layers

Acknowledgements

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